COMPUTER AIDED INTERACTIVE PRESSURE VESSEL DESIGN

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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To my beloved father and mother

Mr. Teoh Lam Ho

Madam Chi Siew Yoong

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ABSTRACT

Designing a pressure vessel using a handbook is troublesome and not interactive. Therefore computer aided software is created to assist the users, however due to business benefit, the computer aided software for designing pressure vessel are not for sale or pricey. This project is to develop an interactive system to design pressure vessels besides the understanding of the algorithm in designing pressure vessel. Results generated by the system were to compare with manual calculations using ASME VIII-1 design code. Beside that, a finite element model was created using the results generated by the system and the maximum stress value in finite element analysis was to compare with theoretical calculation. This project includes comparison studies to compare self defined material with material library, comparison for self defined load with load from substance library and comparison for substance library liquid with substance library gas. Software Microsoft Visual Basic 6.0 is used for the purpose of building the interactive interfaces and processing the data. The system applied formulae from ASME VIII-1 design code and the finite element analysis is using software ALGOR V16. As a conclusion, designing a pressure vessel using computer aided tool is easier and interactive beside low time consumption, therefore, the project Computer Aided Interactive Pressure Vessel Design is able to contribute to the human kind beneficial and should extend the study to become a tool that able to design for all kind of pressure vessel.

ABSTRAK

Proses mereka bekas tekanan menggunakan buku panduan adalah sukar dan tidak interaktif, maka perisian alat bantuan komputer telah dicipta untuk membantu pengguna dalam menyelesaikan masalah tersebut. Namun disebabkan kepentingan dalam perniagaan, perisian tersebut selalunya sulit ataupun dijual dengan harga yang mahal. Kajian ini bertujuan untuk mecipta satu sistem yang interaktif di samping memahami algoritma dalam rekaan bekas tekanan. Untuk memastikan sistem tersebut memberikan hasil yang tepat, hasil daripada sistem tersebut akan dibandingkan dengan pengiraan manual dalam kod ASME VIII-1. Perbandingan juga dilakukan untuk teori dengan analisis unsur terhingga dalam model yang direka menggunakan data daripada sistem. Kajian turut dilakukan untuk membuat perbandingan di antara bahan logam yang didefinisikan oleh pengguna dengan bahan logam daripada perpustakaan bahan logam, perbandingan di antara beban (tekanan dalam) yang didefinisikan oleh pengguna dengan beban yang dijana daripada perpuskataan bahan dan perbandingan di antara perpustakaan bahan cecair dengan perpustakaan bahan gas. Perisian Microsoft Visual Basic 6 digunakan untuk membuat pengantara muka dan pemprosesan data. Pengiraan di dalam sistem menggunakan formula dari Kod ASME VIII-1 dan perisian ALGOR V16 digunakan untuk tujuan analisis unsur terhingga. Sebagai kesimpulan, mereka bekas tekanan menggunakan alat batuan computer adalah menyenangkan, interaktif dan jimat masa, nescaya projek alat batuan reka bekas tekanan interaktif adalah bermanfaat dan kajian seharusnya diteruskan supaya projek ini mampu mereka untuk semua jenis bekas tekanan.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Pressure vessels are leak proof containers used to hold gases or liquids at a pressure different from the ambient pressure. The end caps fitted to the cylindrical body are known as heads.

Pressure vessels are used in various fields such as chemical industry, pharmaceutical industry, oil and fuel industry, and plastic industry. Other example of pressure vessels are diving cylinder, recompressed chamber, distillation towers, nuclear reactor vessel, hydraulic reservoir and storage vessels for liquefied gases such as ammonia and chlorine.

An inadequately designed pressure vessels are hazardous and can cause lose of life. Figure 1.1 shows an accident due to inadequately designed pressure vessel, killing 58 persons and injured 117 others. Therefore, design codes are being introduced for the pressure vessel design, safety factor is applied in the design to offer higher reliability of the pressure vessel. Commonly used design codes are ASME Boiler and Pressure Vessel Code, the Pressure Equipment Directive of EU (PED), Japanese Industrial Standard (JIS), CSA B51 in Canada, AS1210 in Australia and other international standards.

Figure 1.1 Shoes factory after boiler explosion of March 20, 1905 [1]

In this research, an interactive pressure vessel design system will be developed. Users will be offered a user friendly and interactive interface to insert the data and the system will generate adequate information to build the pressure vessel. For example the user provides length and diameter, thus the system will generate the maximum capacity for the pressure vessel. Beside that, users no need to provide density for each material used since the system will have a list of materials together with density to be chosen in building the pressure vessel.

The system is developed base on ASME Code Section VIII, Division 1. Theoretical calculation and finite element analysis will be used to support this study.

1.2 Problem Statement

Most of the methods available to design pressure vessel are in handbook where they are troublesome and not interactive. Although there are computer aided pressure vessel design available in the market, but due to business benefit, the system may not be saleable or pricey. In addition the formulas and concepts applied in the system are always unknown by the users.

1.3 Objectives

i. To build an interactive system using computer programming system to design pressure vessel.
ii. To compare results of design analysis in the system with the ASME VIII-1 design code
iii. To validate the results in the system using theoretical calculation and finite element analysis.

1.4 Project Scopes

i. To build an interactive computer aided pressure vessel design using Microsoft Visual Basic 6.0
ii. To build pressure vessel design system according to rule, ASME Code section VIII-1
iii. To compare results of design analysis in the Interactive Computer Aided Pressure Vessel Design System with the ASME VIII-1 design code.
iv. To compare the result in theoretical calculation with finite element analysis (ALGOR V16).

1.5 Project Limitations

i. Design by rule, ASME Code section VIII-1
ii. Cylindrical horizontal orientated
iii. Only subjected to static internal load
iv. Corrosion allowance is zero
v. Weldments efficiency is considered 100%
vi. No attachments/ special components on the pressure vessel
vii. Three types of head (Hemispherical, Ellipsoidal and Torispherical head)

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this section, design rules in ASME code VIII-1, allowable stress, calculations of internal pressure and hoop stress theory will be reviewed. ASME Code Section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels by utilizing formulas, charts, tables and graphs to establish the minimum thickness of pressure vessel.

2.2 Establishing Minimum Shell Thickness

ASME code section VIII-1 is used to establish the minimum thickness in the pressure vessel design. ASME code section VIII-1 is chosen in this study because ASME design code is one of the most widely used in the world and its reliability. Below is the utilities used to design pressure vessel by ASME Code VIII-1.

2.2.1 Establishing Minimum Shell Thickness by Table and Chart

Table 2.1 is used to establish minimum shell thickness for joint efficiency = 1.0, allowable stress value = 13800 psi and unit in Inches.

Table 2.1: Shell thickness table [1]

INSIDE DIAMETER, IN.									
	12.	18.	24.	30.	36.	42.	48.	54.	60.
psi									
15	0.007	0.010	0.013	0.016	0.020	0.023	0.026	0.029	0.033
20	0.009	0.013	0.017	0.022	0.026	0.030	0.035	0.039	0.044
25	0.011	0.016	0.022	0.027	0.033	0.038	0.044	0.049	0.054
30	0.013	0.020	0.026	0.033	0.039	0.046	0.052	0.059	0.065
35	0.015	0.023	0.030	0.038	0.046	0.053	0.061	0.069	0.076
40	0.017	0.026	0.035	0.044	0.052	0.061	0.070	0.078	0.087
45	0.020	0.029	0.039	0.049	0.059	0.069	0.078	0.088	0.098
50	0.022	0.033	0.044	0.054	0.065	0.076	0.087	0.098	0.109

Steps to establish minimum shell thickness:

1. Determine the right table according to the desired joint efficiency.
2. Locate the desired diameter.
3. Locate the desired pressure.
4. Read the thickness value corresponding to the diameter and internal pressure.

Table 2.1 is based on allowable stress value 13,800 psi. For other stress values, the thickness read is multiply by the following constant factors in Table 2.2 or factors read from the graph. Figure 2.1 shows graph for constant factor versus stress.

Table 2.2: Constant factor at various stresses [1]

Stress, psi	11300	12500	13800	15000	16300	17500	18800
Constant	1.224	1.105	1.000	0.919	0.846	0.787	0.733

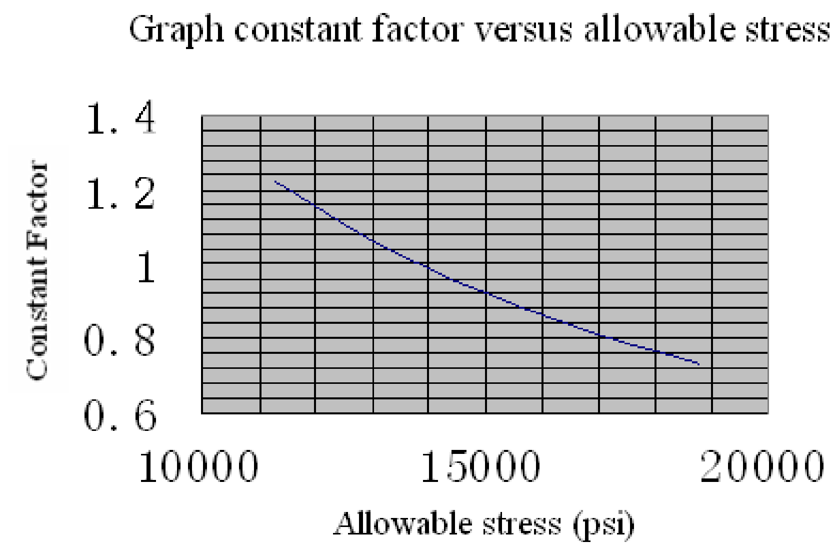

Figure 2.1 Constant factor versus stress [1]

If a constant factor for an allowable stress is not given, equation 2.1 [1] is applied:

$$\text{Constant factor} = \frac{14178}{(\text{Allowable stress})^{1.003}} \tag{2.1}$$

2.2.2 Establishing Minimum Shell Thickness by Formulae

In the Beer [2] studies, an equation applying Hoop stress concept is derived to establish minimum shell thickness in a thin cylinder, given by:

$$t_s = \frac{PR}{SE}$$

where t_s = minimum shell thickness
P = internal pressure
S = allowable stress
E = joint efficiency
R = inside radius

Figure 2.2 shows the Hoop stress induced on the circumference section when an internal pressure applied on the pressure vessel.

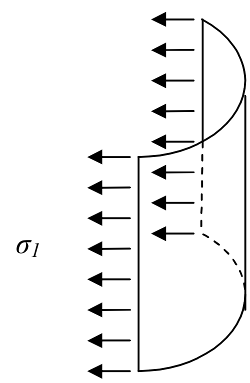

Figure 2.2 Hoop stress, σ_1 [2]

ASME applied equation 2.2 to establish minimum shell thickness [2].

$$t_s = \frac{PR}{SE + 0.6P} \tag{2.2}$$

The difference is the additional term of 0.6*P* in the denominator. This term was added by the ASME to take into consideration of the nonlinearity in stress that develops in thick cylinder [2]. This make the equation is valid for thin and thick cylinder.

A more accurate equation that determines the thickness in a thick cylinder, known as Lamé's equation, is given by:

$$t_s = R\,(Z^{0.5} - 1)$$

where $$Z = \frac{(SE + P)}{(SE - P)}$$

A sample problem is used to compare the difference using equation in ASME code and Lamé's equation.

Sample problem [2]:
Calculate the required shell thickness of an accumulator with P = 8000psi, R = 20in, S = 20000psi and E = 1.0.

Equation in ASME Code

$$t_s = \frac{PR}{SE - 0.6P}$$
$$t_s = \frac{(8000)(20)}{(20000)(1) - 0.6(8000)}$$
$$t_s = 10.526\text{in}$$

Lamé's equation

$$Z = \frac{(SE + P)}{(SE - P)}$$
$$Z = \frac{(20000 + 8000)}{(20000 - 8000)}$$
$$Z = 2.3333$$

$$t_s = R\,(Z^{0.5} - 1)$$

$$t_s = 20\,(2.3333^{0.5} - 1)$$
$$t_s = 10.550\text{in}$$

The comparison demonstrates the accuracy of equation in ASME code over a wide range of R/t ratios.

2.3 Establishing Minimum Head Thickness

Computer Aided Interactive Pressure Vessel Design System that will be developed in this project provides three heads to be chosen by user. They are Hemispherical, Ellipsoidal and Torispherical head.

2.3.1 Minimum Head Thickness for Hemispherical Head

Hemispherical head having sphere shape which is the ideal shape for a head, because the pressure in the vessel is divided equally across the surface of the head.

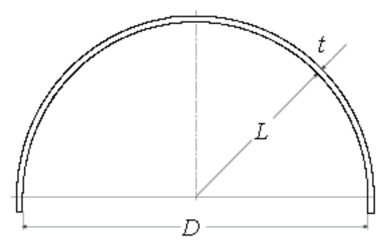

Figure 2.3 Hemispherical head

Minimum head thickness, t_h [1] of a thin spherical shell due to internal pressure is given by:

$$t_h = \frac{PR}{2SE - 0.2P} \tag{2.3}$$

where t_h = minimum head thickness
P = internal pressure
S = allowable stress
E = joint efficiency
R = inside radius

As the ratio t/R increase beyond 0.356, the thickness given by (2.3) becomes non conservative. The ASME VIII-1 equation for thick spherical shell [2] is given by:

$$t_h = R\,(Y^{1/3} - 1) \tag{2.4}$$

where $$Y = \frac{2(SE + P)}{(2SE - P)}$$

2.3.2 Minimum Head Thickness for Torispherical Head

Common Torispherical head can be approximated by a spherical radius, L of 1.0D and a knuckle radius of 0.06D [3].

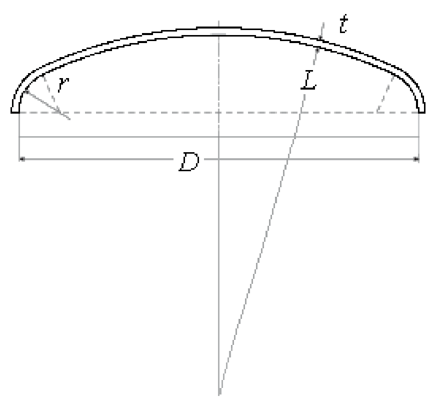

Figure 2.4 Torispherical head

Minimum head thickness, t_h [1] is obtained from the following equation:

$$t_h = \frac{0.885PL}{SE - 0.1P}$$

Where $L = D + 2t$